

Fig. 1. The X-ray astronomy satellite ASCA.

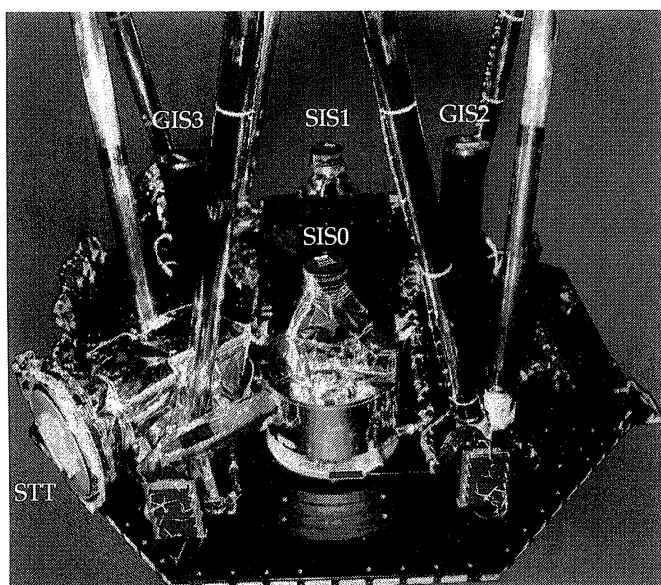


Fig. 3. The focal plane detectors mounted on the base plate of the spacecraft. For SIS and GIS, see text. STT is the star tracker. A part of the truss structure of the extensible optical bench is also seen.

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## The X-Ray Astronomy Satellite ASCA

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### Abstract

ASCA is a high-throughput X-ray astronomy observatory which is capable of simultaneous imaging and spectroscopic observations over a wide energy range 0.5–10 keV. The scientific capabilities of ASCA and some aspects related to its operation and observations are briefly described.

**Key words:** Instrumentation — Spacecrafts — X-rays: general

### 1. Introduction

Astro-D, the fourth Japanese X-ray astronomy satellite, was launched by the Institute of Space and Astronautical Science (ISAS) on 1993 February 20, with the M-3S-II rocket, and put into an approximately circular orbit with a perigee and apogee of 520 and 620 km, respectively, and an inclination of  $31.^\circ 1$ . The orbital period is approximately 96 min.

Astro-D was then renamed ASCA. The Japanese characters (kanji) for ASCA literally represent a “flying bird,” but more appropriately it is the name of an ancient era of Japan during which the country was modernized and culture flourished. It is also meant to be an acronym for “Advanced Satellite for Cosmology and Astrophysics.” The configuration of ASCA in orbit is shown in figure 1 (see page L37).

An extensive collaboration between Japanese and U.S. scientists has been carried out in the joint developments of the X-ray telescopes, the X-ray CCD cameras, and computer software. Tracking support is also provided by the NASA Deep Space Network stations, which substantially enhances the down-link coverage.

The spacecraft mass is 417 kg, and its length is 4.7 m along the telescope axis. The spacecraft is three-axis stabilized. The pointing accuracy is approximately  $30''$  with a stability of better than  $10''$ . Orientation of the spacecraft is limited by the power constraint that the direction of the solar paddles must be within  $30^\circ$  from the sun. This limits the observable sky at a time in a belt within which the sun angle is between  $60^\circ$  and  $120^\circ$ . The entire sky is accessible every half year.

### 2. Scientific Instrumentation of ASCA

The scientific instrumentation of ASCA consists of X-ray telescopes and focal plane detectors, as described below.

#### 2.1. X-Ray Telescopes

ASCA carries four identical grazing-incidence X-ray telescopes (XRT) each equipped with an imaging spectrometer at its focal plane. The telescope utilizes multi-nested (119 layers) thin-foil conical optics, a technology developed by Serlemitsos (1981). This technology allows maximum use of the aperture for X-ray reflection, and enables a light-weight large-effective-area X-ray telescope. The effective area of XRTs as a function of energy is shown in figure 2. The angular resolution of the telescope is modest, with a half power diameter (diameter which encircles 50% of the photons of a point source image) of approximately  $3'$ . However, the point spread function has a cusp-shaped peak, and 20% of photons are concentrated within a circle of  $1'$  diameter, producing a sharp image core. This feature allows us to resolve two sources separated by  $1'$ .

The focal length of the telescopes is 3.5 m. These telescopes are mounted on an extensible optical bench. Because of the limited length available within the rocket nose fairing, the optical bench was “telescoped” inside the spacecraft during launch and extended 1.2 m in orbit to achieve the focal length.

The telescopes aboard ASCA were prepared jointly by the groups of NASA Goddard Space Flight Center, Nagoya University, and ISAS.

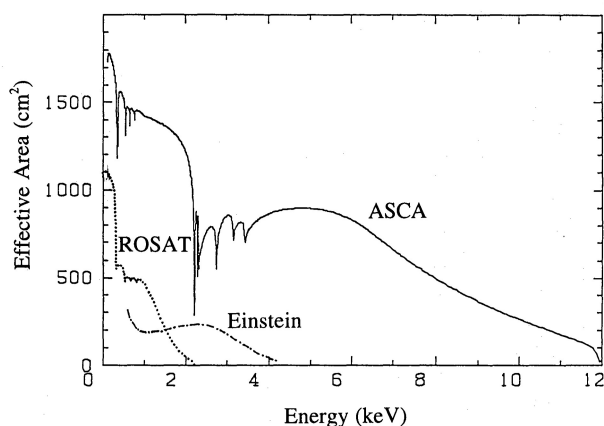


Fig. 2. Total on-axis effective area for four sets of mirrors of ASCA as a function of X-ray energy, in comparison with those of the Einstein Observatory and ROSAT.

## 2.2. Focal Plane Detectors

The focal plane detectors are two CCD cameras (Solid-state Imaging Spectrometer, or SIS) and two gas scintillation imaging proportional counters (Gas Imaging Spectrometer, or GIS). Figure 3 (see page L37) shows these detectors mounted on the base plate of the spacecraft. All four detectors are operated simultaneously all the time, and data obtained from each of them are separately available.

The SIS has superior energy resolution, with resolving power  $E/\Delta E$  of  $\sim 50$  at 6 keV, and  $\sim 20$  at 1.5 keV, and is sensitive down to 0.5 keV. ( $\Delta E$  is FWHM.) The GIS energy resolving power is  $\sim 13$  at 6 keV and  $\sim 7$  at 1.5 keV. The GIS is practically insensitive below  $\sim 1$  keV because of a 10  $\mu\text{m}$ -thick beryllium window, but has a higher detection efficiency above  $\sim 3$  keV than does the SIS.

The SIS has a square field of view (f.o.v.) of  $20' \times 20'$ , whereas the GIS has a larger circular f.o.v. of 50' diameter. With respect to  $E/\Delta E$  and f.o.v., therefore, the SIS and the GIS have complementary advantages.

The SIS detectors and the associated data handling system were prepared jointly by the groups of Massachusetts Institute of Technology, Pennsylvania State University, Osaka University, and ISAS. The GISs were prepared by the groups of University of Tokyo and ISAS.

More detailed descriptions of the X-ray telescopes (XRT) and the focal plane instruments (SIS and GIS), as well as their performance characteristics, will be presented in separate papers.

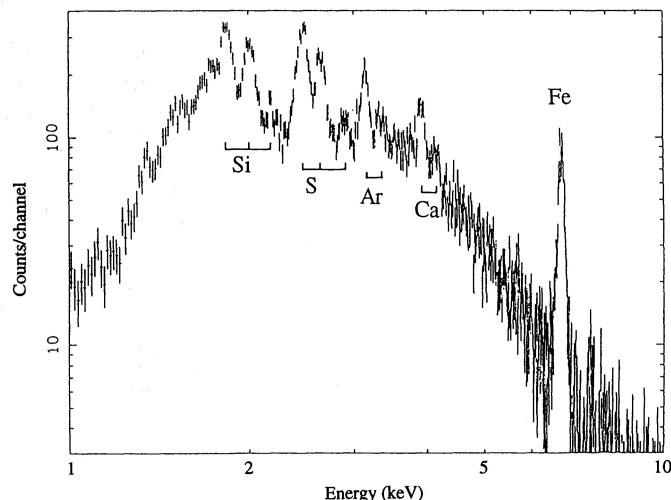


Fig. 4. X-ray spectrum of the supernova remnant W49B obtained with the SIS detector on board ASCA. The  $K_{\alpha}$ - and  $K_{\beta}$ -lines from helium-like ions and the  $K_{\alpha}$ -line from hydrogen-like ions of Si and S, the  $K_{\alpha}$ -line from helium-like ions and the  $K_{\alpha}$ -line from hydrogen-like ions of Ar, Ca, and the  $K_{\alpha}$ -line from helium-like ions of Fe are clearly distinguished.

## 3. Scientific Capabilities

ASCA is an X-ray astronomy observatory which, for the first time, is capable of performing imaging and spectroscopic observations simultaneously over a wide energy range 0.5–10 keV.

There have been two high-sensitivity imaging missions before ASCA: the Einstein Observatory (Giacconi et al. 1979) and ROSAT (Trümper 1990). The spatial resolution of ASCA is comparable to the Imaging Proportional Counter (IPC) of the Einstein Observatory, whereas the ROSAT Position-Sensitive Proportional Counter (PSPC) has much better spatial resolution. ROSAT also has significantly higher source detection sensitivity than does ASCA, which is source-confusion limited (see below). On the other hand, the Einstein Observatory and ROSAT are limited to narrower energy bands than ASCA, as the Einstein Observatory is limited to  $< 4$  keV, and ROSAT  $< 2$  keV.

The ASCA instruments cover the most important energy band for plasma diagnostics, because the K-lines and the K-absorption edges from oxygen through iron (and also the L-lines of iron) at various ionization stages all lie within this band. The SIS of ASCA can individually resolve all major lines (except the L-line complex around 1 keV), as demonstrated with the example of the X-ray spectrum of a supernova remnant exhibited in figure 4 shows. Motion of plasma of the order or greater than 1000  $\text{km s}^{-1}$  can be measured significantly from

Doppler shift of the line energies. Also, ASCA has a much larger effective area, hence a much larger photon collection power, than the Einstein Observatory and ROSAT (see figure 2), which is an advantage for the detailed line spectroscopy requiring large enough numbers of photons for meaningful statistical precision. These capabilities of ASCA not only enable us to determine more accurate temperature than before, and to study chemical abundances and dynamics of thermal plasmas, but also allow diagnostics of accreting matter around compact objects through studies of emission and absorption features.

Spatially-resolved spectroscopy with ASCA provides a powerful means for the investigations of spatially extended plasmas in supernova remnants, galaxies, and clusters of galaxies.

A wide energy-band coverage is essential for the study of the nature of emission, thermal or non-thermal origin, from the spectral shape of the continuum. Together with its high sensitivity, ASCA will allow us to measure the spectra of faint sources beyond the energy ranges of the Einstein Observatory ( $< 4$  keV) and ROSAT ( $< 2$  keV). New discoveries of heavily absorbed sources which were not detectable with the limited bandpass of these previous satellites can also be expected.

#### 4. Performance Verification

After launch, various observations were carried out primarily for the performance verification (PV) of the instruments in orbit. About 150 sources of various astronomical classes have been observed during the PV phase. The phase of program in which general observers can participate in ASCA, based on peer-reviewed proposals, began in 1993 October.

The non-X-ray background rates were measured with the observations of the night-side earth and confirmed

to be very low:  $5 \times 10^{-4}$  counts  $\text{cm}^{-2} \text{s}^{-1} \text{keV}^{-1}$  and  $6 \times 10^{-4}$  counts  $\text{cm}^{-2} \text{s}^{-1} \text{keV}^{-1}$  per detector for GIS and SIS, respectively. The background showed an approximately flat spectrum above 1 keV with some weak fluorescent lines generated inside the detectors.

The source detection limit can be estimated from the observed spectra of the "blank" sky (dominated by the cosmic X-ray background). For a typical exposure of 40 ks, the Poisson fluctuation (photon statistics) still dominates the genuine fluctuation of the cosmic X-ray background. In this case, the preliminary estimate of the  $5\sigma$  detection limit for a single detector is roughly  $4 \times 10^{-14}$  erg  $\text{cm}^{-2} \text{s}^{-1}$  in the range 2–10 keV, for a source with a non-absorbed Crab-like spectrum. The detection limits of the GIS and the SIS are approximately the same. For much deeper exposures, the effect of source confusion will become important. This effect is currently being investigated.

From the results obtained so far, we can estimate that detailed spectroscopic studies are possible for the sources of flux  $> 10^{-12}$  erg  $\text{cm}^{-2} \text{s}^{-1}$ , and coarse spectra can be obtained down to a flux level of several times  $10^{-14}$  erg  $\text{cm}^{-2} \text{s}^{-1}$ .

ASCA is the result of years of hard and dedicated effort by many scientists, engineers, and technicians in ISAS, NASA, universities, and industry. The authors are grateful to all of them. We also thank the ISAS launch team for successfully placing ASCA in orbit.

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